

number of compositional techniques have been tried.

Is the idea of efficient voice leadings, then, a hopelessly dated concept? Not necessarily, says music theorist Richard Cohn, though it's difficult to generalize about modern music. Schönberg himself wrote a pedagogical treatise in

which he describes how to lead voices. And given the chords he chose to use, Schönberg often took pains to connect them economically.

Steven K. Blau

Reference

1. D. Tymoczko, *Science* **313**, 72 (2006).

Tectonic-plate flexure may explain newly found volcanoes

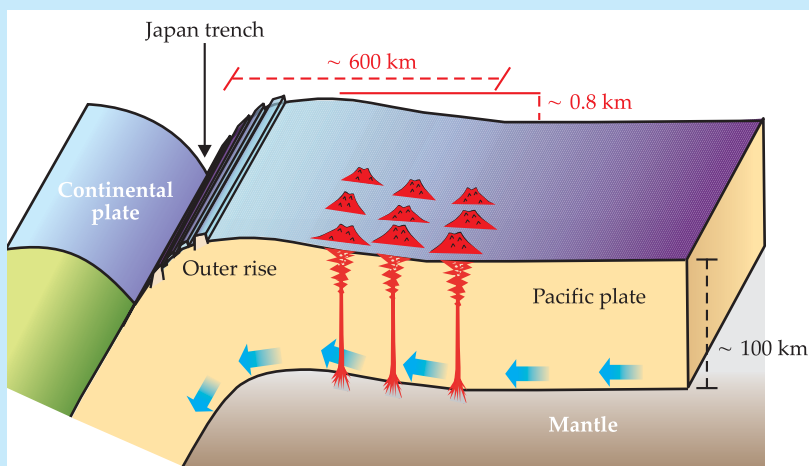
The form and chemical composition of their lavas add to our growing understanding of where on Earth volcanoes can form.

The reduction of pressure in the mantle is a central reason behind Earth's volcanism. Mantle rock that rises adiabatically to a low enough pressure melts without any added heat source. The ascent may be actively driven by convection, as in mantle plumes, where hot, buoyant jets from the deep interior are thought to provide a rich source of material to fuel the volcanism. Or it may be passive, as at mid-ocean ridges, where magma forms from the upwelling of rock into the gaps left by the spreading of tectonic plates. Deglaciation can also trigger volcanic pulses, as it did in Iceland at the end of the last ice age when the elastic plate rebounded from the melting of the ice cap. Meteorite impacts that excavate large craters at Earth's surface are yet

another cause of pressure release.

A group of researchers from Japan and the US has now discovered a class of volcanoes that apparently formed from pressure release of a different kind—one based on the flexure produced in one lithospheric plate as it is forced beneath another. Naoto Hirano of the Tokyo Institute of Technology and colleagues found clues to the volcanoes a few years ago during deep-sea exploration off the coast of Japan. They analyzed what turned out to be young basalt—erupted lava—hundreds of kilometers from where the Pacific plate dips below Japan.

“Complete serendipity” is how coworker and geochemist Stephanie Ingle of the University of Hawaii describes their find. The researchers were



When a dense, thick oceanic plate collides against a buoyant continental one, the oceanic plate sinks beneath it. In the case pictured here, the Pacific plate is elastic enough to bend severely as it inexorably moves westward and down under Japan, but stiff enough that it may also flex upward. Magma formed in the mantle underneath, or preexisting in small pockets, then seeps into the resulting cracks and microfissures thought to accompany the flexure. Little underwater volcanoes, or seamounts, each roughly a kilometer wide and 50 meters high, erupt in response. Arrows indicate the plate's motion. (Adapted from ref. 1.)

investigating sediment compositions, not volcanism. And each underwater volcano, or seamount, produced less than 1 cubic kilometer of lava, a millionth of the volume that has erupted from the Hawaiian islands. It was only by tracking similarities in sonar data during their recent survey¹ that Hirano and his crew could locate the small seamounts and their lava beds. During their expedition, the researchers used a manned submersible—the *Shinkai* (Japanese for “deep sea”)—to sample basalt from the sea floor.

What makes the discovery off Japan intriguing is that volcanism there is unexpected. The seamounts are young, some less than a million years old, and erupt through a cold plate dating from 135 million years ago. Old plate is thick—estimated to reach nearly 100 km in this region of the Pacific Ocean, far from the tectonic boundaries where volcanism typically occurs. High concentrations of a few trace elements in the basalt signaled that only small amounts of melting had occurred at

depths greater than 100 km. Rare-gas compositions confirmed that the melting originated in the upper mantle, or asthenosphere.

Current models of Earth hold that minerals found in the asthenosphere at depths around 150 km below the sea floor should remain solid. But the presence of even small concentrations of volatile materials such as carbon dioxide and water lowers the melting temperature of mantle rock. Melting at those depths would then supply the additional magma needed to percolate to the surface through so thick a plate. The morphology of the basalt dredged up by Hirano and company—in particular, the embedded pores and vesicles—bore out the presence of those volatiles. As the melt rose through the lithosphere, dissolved gases in the magma changed phase to form bubbles—much like carbon dioxide bubbles in a newly opened bottle of beer. Further decompression of the gaseous bubbles provided explosive force to the eruption.

To explain the presence of the volca-

noes, arranged on the sea floor in rows parallel to the trench off Japan, Hirano and his colleagues propose that a gentle buckling of the lithospheric plate (east of the outer rise) accompanies the severe bend formed as the Pacific plate slides under Japan, as pictured on page 21. The plate's slight upward bulge then depressurizes the mantle underneath to create magma, which squeezes through cracks and stress fractures at the bottom of the plate and drains upward.

Most geophysicists imagine that the melt percolates along microscopic grain boundaries, at least initially. Although buoyant, the melt still has to overcome the friction generated as it flows around rocky grains. The eventual formation of a macroscopic crack appears essential to prevent the melt from losing heat and freezing on its way to the surface. The youngest volcanoes appear farthest from the trench, where stress conditions make the plate ripe for fracture. Older ones appear closer to the trench.

The Pacific plate cools nonuniformly as it ages, so it's no surprise that it might

physics update

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Flexible, large-area sensors and microphones made with thin sheets of packaging foam may be possible. Via a simple charging process, the foam can be turned into a ferroelectret, a material that combines the permanently polarized electric dipoles of a ferroelectric substance with a large piezoelectric effect whereby a slight deformation generates a significant voltage. (See the article on ferroelectrets in *PHYSICS TODAY*, February 2004, page 37.) Physicists at the Johannes Kepler University (Linz, Austria) and at Princeton University have shown that ferroelectret films can muster electric fields big enough to activate a thin-film FET made of amorphous silicon. Combining those two technologies—ferroelectrets and FETs—the researchers have demonstrated working versions of flexible microphones and touch sensors, about a centimeter across and 70 microns thick. Lead investigator Ingrid Graz says that their new form of soft electronics can be scaled up and may be useful for producing items like flexible paper-thin keyboards, flexible microphones for mobile phones, active noise-control devices, toys, hearing aids, and surround-sound systems. Someday it might even be used as prosthetic skin. (I. Graz et al., *Appl. Phys. Lett.* **89**, 073501, 2006.) —PFS

Bloch oscillations measure gravity. In 1929 Felix Bloch predicted that electrons in a periodic crystal potential subjected to a weak electric field would not be linearly accelerated; rather, they would oscillate around their individual positions. Although never seen in actual crystals because of lattice defects, Bloch oscillations are observable with cold atoms in an optical lattice (see *PHYSICS TODAY*, July 1997, page 30, and

August 2004, page 25). Experimenters at the University of Florence (Italy) have set up such a system and measured gravity on the micron scale. To do that, they cooled bosonic strontium-88 atoms—which not only have no angular momentum in the ground state but also enjoy extremely weak atom-atom interactions—to a mere 400 nK and loaded them into a vertically oriented optical lattice. Because the ⁸⁸Sr atoms formed a nearly ideal gas, the system remained coherent and stable for a remarkably long time, about 7 seconds. For each atom during that time, the physicists observed roughly 4000 oscillations and 8000 photon momenta coherently transferred. In the end, they measured the gravitational acceleration to be 9.80012(5) m/s². According to team leader Guglielmo Tino, unlike gravity-measuring experiments that use torsional balances or cantilevers, the Florence approach measures gravity directly and over shorter distances. In addition, the experiment can take place within microns of a surface, enabling future explorations of the Casimir force and deviations from Newtonian gravity. (G. Ferrari et al., *Phys. Rev. Lett.* **97**, 060402, 2006.) —PFS

Pyramid-shaped nuclei. A group of European physicists believe they can solve the mystery behind dozens of nuclear experiments carried out more than a decade ago. The experiments—conducted with various detectors, at various energies, and involving various nuclear species—produced such puzzling results that many of the experimenters turned their attention to the study of other systems. Now, Jerzy Dudek of University Louis Pasteur (Strasbourg, France) and his colleagues at Warsaw University (Poland) and the Autonomous University of Madrid (Spain) think that the old results can be explained by nuclei having tetrahedral symmetry. Just as so-called magic nuclei have the right number of neutrons and protons to readily form stable spherical nuclei, so too can such magic numbers be expected for forming pyramidal nuclei. Stable, in this case, means that the state persists from 10¹² to 10¹⁴ times longer than

contract and crack in places. Indeed, the floor of the Pacific Ocean is littered with thousands of volcanic seamounts, rifts, and faults, in various orientations and alignments.² And other volcanoes, such as ones in the islands of western Samoa, are thought to form from a flexed plate, though in a different tectonic context, and display chemical signatures similar to those found in lavas sampled off the Japanese coast. Some theorists argue that lithospheric flexing may even explain a periodicity in the spacing of volcanic islands.

Models support the idea that the lower part of the plate stretches, but Brown University's Donald Forsyth questions whether the stresses created several hundred kilometers from the subduction zone are indeed large enough to fracture the rock. Why an eruption should occur on a plate whose upper regions are compressed is also puzzling. Magma can, however, force its way to the surface by forming and expanding its own crack, especially if the magma is volatile-rich, as it appears

to be here. Still, Forsyth and other researchers agree that the newly found seamounts, small as they are, offer a compelling example of volcanism in part of Earth that is not one of the usual volcanic suspects—a mid-ocean ridge, an upwelling plume, or an island arc.

Together, however, the mechanisms of depressurization and the flux of volatiles may not be enough to explain the eruptions. Based on the geochemistry of the lavas, Hirano argues that the seamounts tap a region of the mantle that contains preexisting small but widely distributed pockets of partial melt. Thermodynamically, that's a reasonable viewpoint, at least in regions where conditions are hot enough for liquid and solid to coexist, says Caltech's David Stevenson. And it may prompt researchers to revisit their interpretation of the seismic low-velocity zone, commonly observed below ocean basins, where signals travel significantly more slowly than they do in surrounding regions of the mantle.

Last year, researchers explained the

low-velocity zone as possibly due to the rheology of olivine—the upper mantle's most prevalent mineral.³ But the presence of small amounts of molten material could also contribute to slow seismic velocities. Minerals in the asthenosphere are unlikely to be perfectly mixed, and the region may well experience thermal gradients and melting anomalies. The implications for volcanism are fascinating: A through-going crack or leaky fault would support volcanism just about anywhere on Earth. Judging from the Japanese seamounts, though, the eruptions might be meager.

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References

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2. See J. H. Natland, E. L. Winterer, in *Plates, Plumes, and Paradigms*, G. R. Foulger et al., eds., Geological Society of America, Boulder, CO (2005), p. 687.
3. U. H. Faul, I. Jackson, *Earth Planet. Sci. Lett.* **234**, 119 (2005).

the typical 10^{-21} seconds for nuclear reactions. In tetrahedral nuclei, up to four nucleons of the same kind (neutrons or protons) could share a single energy level instead of the customary one or two nucleons permitted by classic nuclear theory. That rule-of-four would inhibit the normally observed decay modes by which nonspherical nuclei throw off energy, usually by emitting gamma rays. The inhibition would explain the puzzling results of earlier experiments. Dudek says that gadolinium-156 and ytterbium-160 are good candidate nuclei for stable pyramidal configurations, and the physicists found tentative evidence for tetrahedral ^{156}Gd . The researchers plan to test their ideas in upcoming experiments. (J. Dudek et al., *Phys. Rev. Lett.* **97**, 072501, 2006.)

—PFS

Methane from the deep could be a significant feedback mechanism in climate change. As oil and gas companies well know, many hydrocarbon deposits lie beneath the sea floor. Over geologic time scales, some oil and gas (primarily methane, CH_4) deposits can slowly seep through cracks in the sedimentary rock and reach the ocean floor, where buoyancy takes over. The ensuing natural oil slick on the ocean's surface then degrades through both bacterial action and evaporation of the volatile chemicals. What's left is a tar residue that sinks back to the ocean floor. This chain of events inspired a team of Earth scientists to examine sea-floor cores, drilled off the coast of California, for deposits of tarry sand as a proxy for CH_4 release. They found several episodes of enhanced CH_4 emission in Earth's history, notably from 16 000 to 14 000 years ago and from 11 000 to 10 000 years ago. Those two eras correspond to periods of globally melting glaciers and rising atmospheric temperatures. The researchers also note that hydrates—semisolid CH_4 agglomerates that can exist in the cold, high-pressure sea-floor environment—are common near hydrocarbon seeps. According to team leader Tessa Hill (University of California, Davis), a possible scenario is that the

hydrates first become unstable due to a warmer ocean bottom at higher pressure from rising sea levels; the roused hydrates then perturb the sea floor to enhance hydrocarbon seepage and CH_4 emission. Because CH_4 is a potent greenhouse gas, global warming increases and brings about further sea-floor instabilities. The natural process is slow to start, but it gathers steam in a positive feedback loop. (T. M. Hill et al., *Proc. Natl. Acad. Sci. USA* **103**, 13570, 2006.)

—SGB

A Google-like approach to mammograms. Knowledge-based computer-assisted detection (KB-CAD) systems, which are increasingly being used in clinical settings, compare a mammogram image with images in a database of known cases of breast cancer. The results of the comparison are then used by a radiologist to aid in the diagnosis. Although they are diagnostically accurate, detailed comparisons become increasingly inefficient as image databases grow. At the recent meeting of the American Association of Physicists in Medicine (AAPM), held in Orlando, Florida, Georgia Tourassi (Duke University) presented a way to speed up the process using the information-theoretic idea of image entropy. An image that is all black or all white has zero entropy; a complex image with a more uniform distribution of different pixel intensity levels has higher entropy. Image entropy can be easily and quickly determined, and that's what the Duke system does first. In a way similar to an internet search engine, the new KB-CAD system first returns a list of database images whose entropies are similar to that of the one under study, then does a detailed comparison on only that subset of images. The database of Tourassi and her colleagues uses images of both normal and cancerous tissue for comparisons. In their tests, a database of 2318 images was quickly whittled down to only 600, and achieved the same performance as the standard KB-CAD method in one-fourth the time. The researchers expect to follow up their pilot study with a larger clinical investigation. (AAPM Meeting Paper TU-D-330A-8.)

—BPS ■